The *Picturephone*® System:

Station Set Components

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The development of the Picturepbone® *station set required the special design of many new electronic components. These include new camera and display tubes for opto-electro conversion, 18 integrated circuits using both silicon and tantalum technologies, and several additional discrete devices. This article reviews the development of these custom designed electronic components.*

I. INTRODUCTION

The *Picturephone* station set[1] is one of the most sophisticated items of station equipment ever provided a Bell System customer for switched two-way communications. In concept, the *Picturephone* station set resembles a commercial closed circuit transmitter and receiver. However, the operating conditions are markedly different and impose special requirements on many of the components. To provide the optical to electrical conversion in the transmitter and the inverse in the receiver, as well as tbe audio and control functions, requires over 900 electrical components in tbe station set. These range from simple passive discrete resistors to the silicon diode array camera tube wbich contains over 500,000 diodes in its approximately 0.2 square inch active target area.

Combinations of hybrid integrated circuits utilizing both silicon and tantalum technologies, silicon monolithic circuits, discrete solid-state devices, and discrete passive components are incorporated on the various circuit boards. Additional components consist of the camera and display tubes and two active non-solid-state devices which are used in tbe high-voltage power supply. The active components used in the display, control, and service units are shown in Fig. 1.

To develop the complex station set circuitry in an orderly fashion, it was necessary to decide early in the design which portions of the circuitry were to be realized in integrated form. Some circuits re-

quired the precision tuning available with tantalum thin-film technology and were designed using hybrid integrated circuits. Other circuits were uneconomical in size and/or cost to be built in discrete form and their designs were realized in monolithic silicon form. In still other circuits it was found that though they could be realized in discrete form, it would be advantageous to utilize the matched characteristics available on silicon chips. Thus integrated circuit designs were used where it made best technical or economic sense to use them. Out of this design effort, undertaken jointly by the Systems Development and Device groups, 33 silicon integrated circuits (SIC) of 18 different designs evolved for *Picturephone* station set use. The most widely used SIC is the building block circuit which is used in seven different applications.

A simplified block diagram of the *Picturephone* station set is shown in Figs. 2, 3, and 4. Those circuits which utilize hybrid and monolithic integrated circuits are marked accordingly.

Several discrete components were custom designed to operate under the special conditions found in the *Picturephone* station set. Included

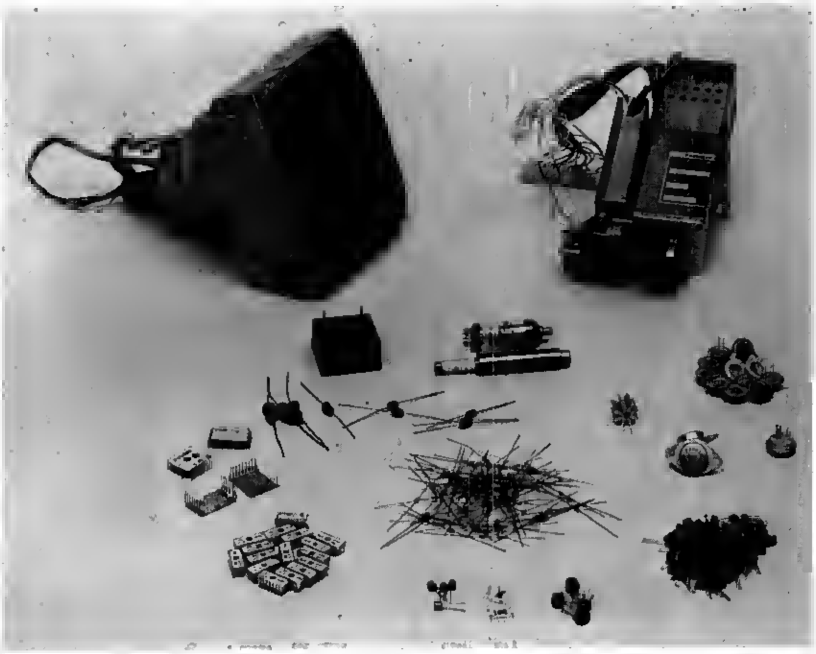

Fig. 1—Station set active components.

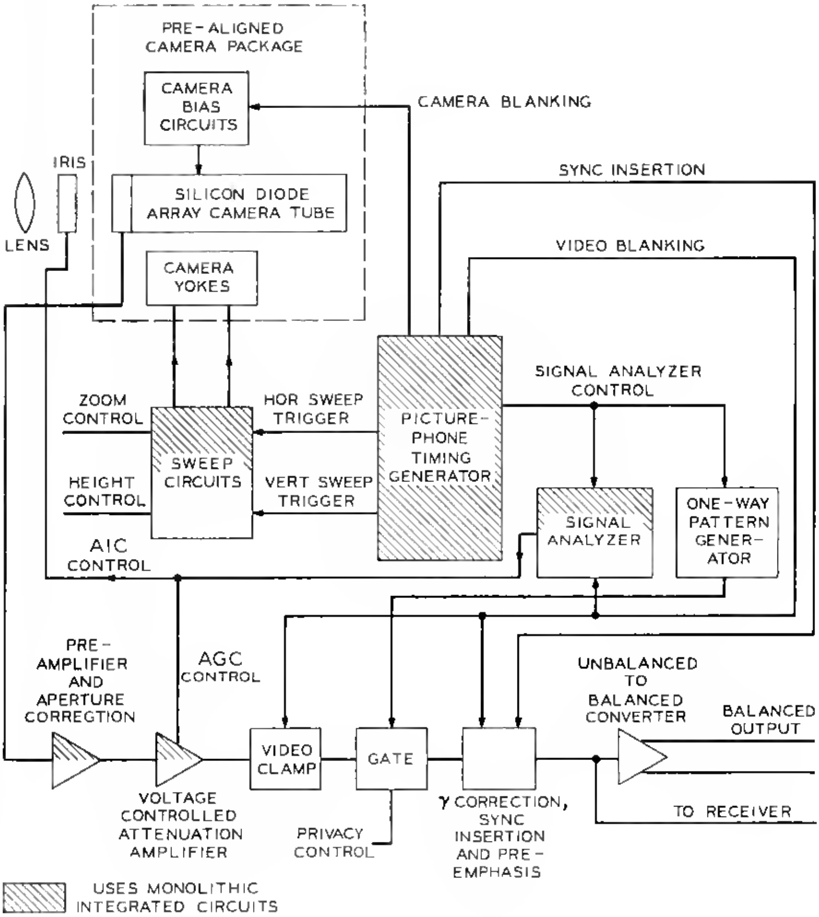

Fig. 2—Transmitter block diagram.

in this category are bipolar transistors, junction field effect transistors, a packaged display tube and a completely interchangeable packaged camera tube. This article will highlight those devices which were custom designed and existing devices which required special characterization for use in the station set.

II. CAMERA TUBE

Several unique properties are required of a camera tube for use in *Picturephone* service.[2-4] Life and reliability must be consistent with

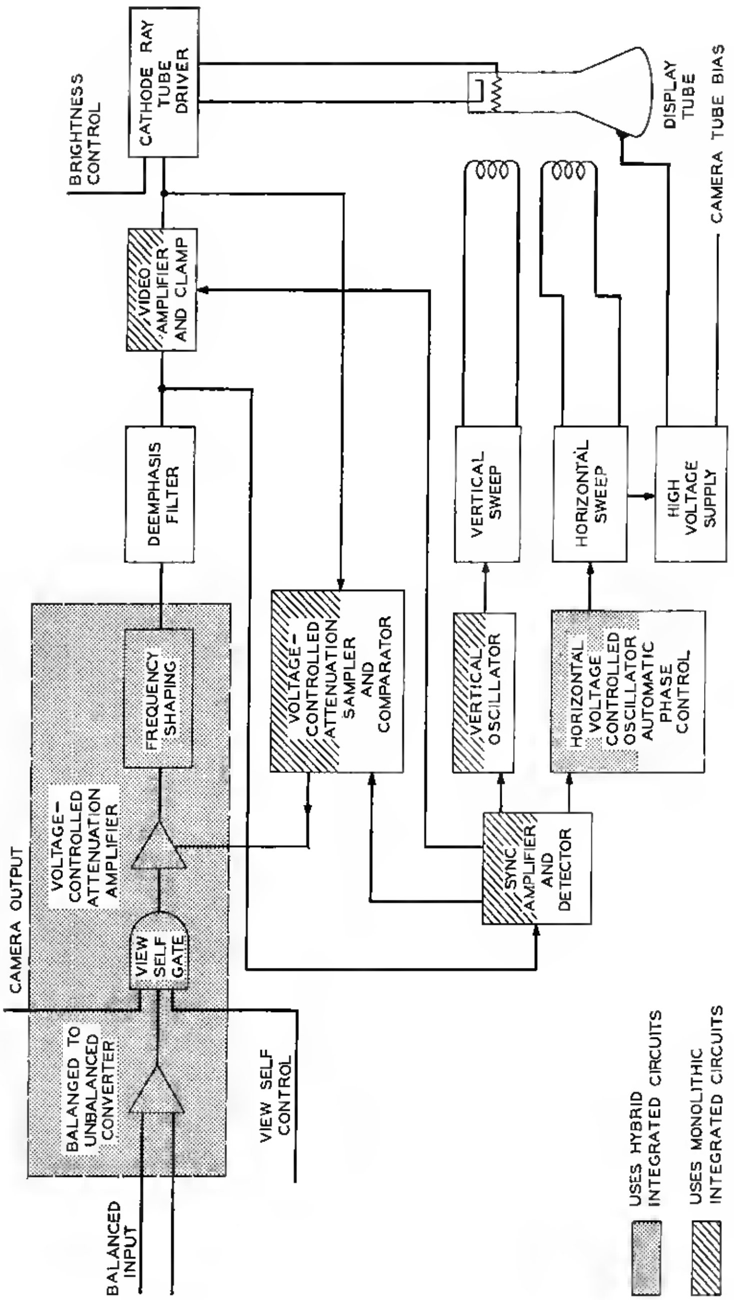

Fig. 3—Receiver block diagram.

Bell System standards. The camera tube must operate in environments where there are bright lights and high temperatures. It must withstand mechanical shock and have the ability to react rapidly when called upon. In meeting these objectives, the required power must be kept to a minimum and the manufacturing cost must be sufficiently low to justify use in *Picturephone* service.

These requirements are fulfilled in the design of the *Picturephone* camera tube. Unlike previous camera tubes which use an amorphous substance as the photoconducting element, this design uses an array of diodes (~525,000 in the scanned area) on a single crystal slice of silicon. This approach results in a target shown in Fig. 5 having the following advantages compared to an amorphous target:

(*i*) It is not damaged by any reasonable light source.
(*ii*) Sensitivity is improved by a factor of at least 3 to 1.
(*iii*) It allows the scan size to be electronically changed without adverse effects.
(*iv*) It possesses a long life.

Figure 6 shows the camera-tube structure which has been designed to hold the silicon target so that it will withstand mechanical shock in excess of 50 G and will be maintained at the temperature of the station set front panel. The electron gun and beam focusing electrodes

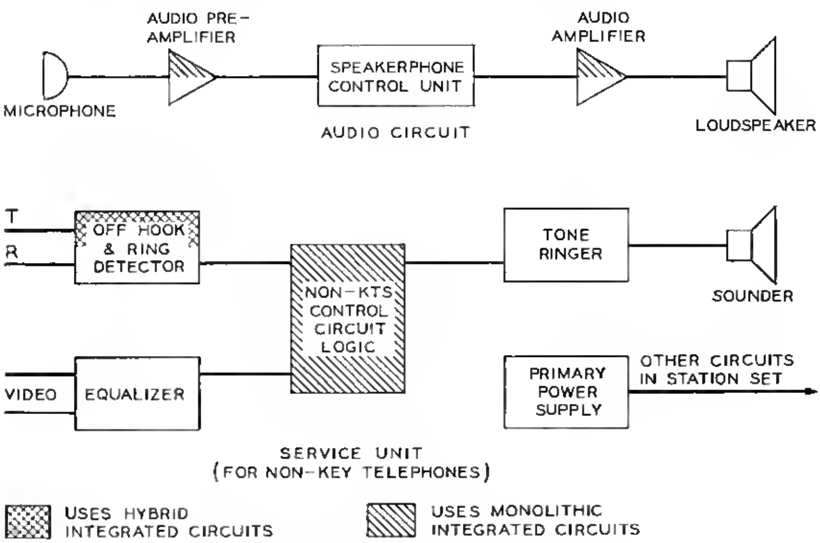

Fig. 4—Block diagram of audio circuit and service unit.

are assembled by brazing the metallic parts to a high alumina ceramic. Halide-free hard glass is used for the envelope and seals are made directly between glass and metal. This technique contrasts with that used in most similar devices, in which a soft metal seal (such as indium) forms an intermediate layer between glass and metal. An advantage of the direct seal between glass and metal is that high processing temperatures can be used which enhance long cathode life.

The cathode has been designed to match the long life expected of the silicon target. A thin layer of nickel is used to coat the electron emissive cathode particles so that the resulting cathode can be operated at a lower temperature for a given current. Use of this coating technique along with the proper nickel base alloy provides a cathode with greater than five-year life expectancy.

Manufacturing techniques and facilities have been designed to enhance reliability. Targets are processed and tubes assembled within laminar flow work benches which are installed within a room fed with filtered air. Assembly operators are garbed in a manner to minimize contamination of the work area. Final tube exhaust is carried out on an oil-free high vacuum station, with ultimate pressure at the time of tube pinch off of about 2×10^{-8} torr.

The physical design philosophy used in the station set has been to provide all units in modular form. Manufacture of the camera tube follows this concept. The required circuits are mounted within the camera package at the tube manufacturing plant. They include deflection coils, magnetic shielding, preadjustments for deflection currents,

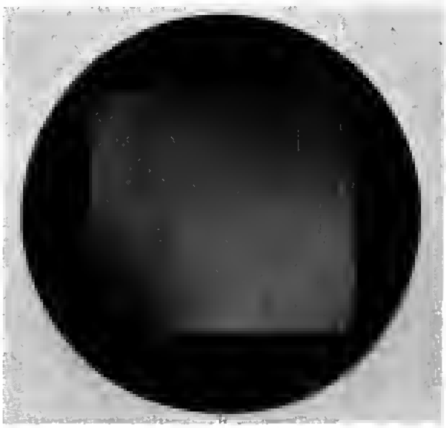

Fig. 5—Camera tube target.

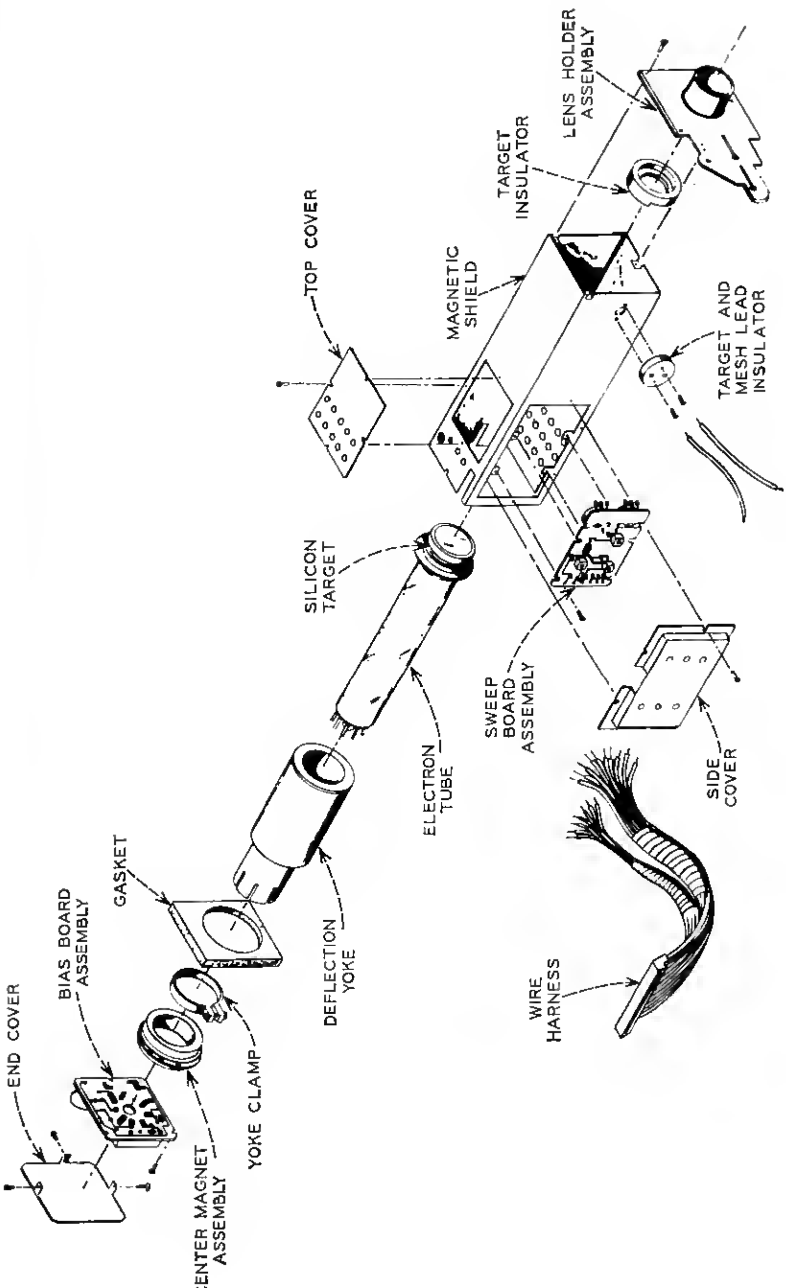

Fig. 6—Close-up view of the camera tube.

raster centering and all tube electrode voltages as shown in Fig. 7. Adjustment of the camera tube will not be necessary when it is mounted in the station set.

The camera tube operates at a peak signal current of 225 nA and has a maximum signal output in excess of 300 nA. At room temperature the dark signal current is about 10 nA. For incandescent light the average sensitivity is 175 nA per 0.1 footcandle. Operation of the set begins almost instantly when a call is initiated or answered; this performance is attained by maintaining the tube at 90 percent of its operating heater voltage during standby periods.

III. DISPLAY TUBE

Requirements on the display tube are also somewhat more stringent than would be found in normal commercial applications. In addition to providing long, unattended life, and shock resistance, the

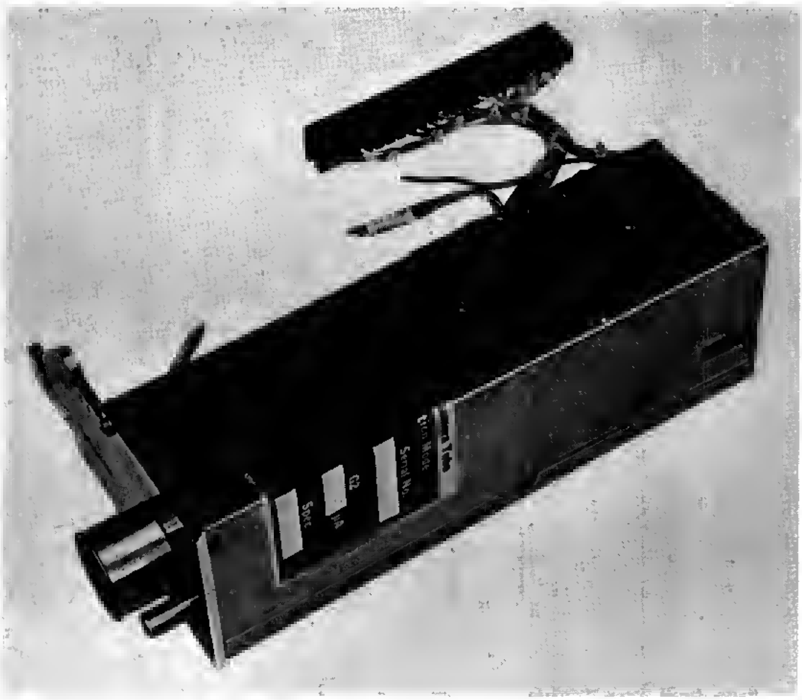

Fig. 7—Assembled camera tube.

potential hazard of the envelope imploding must be considered for personnel protection. Implosion protection is provided by applying a laminated safety panel over the exposed face of the tube. Additional implosion protection is provided for the funnel portion of the tube by completely encapsulating it in a polyurethane jacket. Since the cured polyurethane material adheres to tbe glass envelope, it prevents collapse of the funnel upon fracture of the display tube.

Tbe display tube is manufactured with a non-browning glass envelope. This insures that long-term bombardment of tbe glass by the high-voltage electron beam will not result in a glass color change which might alter the spectral quality of the emitted light. Conventional settling techniques are used to deposit a white phosphor. To increase radiated light and to protect the pbosphor layer from ion damage, the bulb is then aluminized.

Assembly of the electron gun consisting of stainless steel parts is performed on laminar flow benches. Cathode techniques, as described for the camera tube, have been used to maximize life capability. To further extend operating life the average catbode current is held to a minimum.

In keeping with the modular concept, the *Picturephone* display tube package shown in Fig. 8 contains the deflection yoke and centering

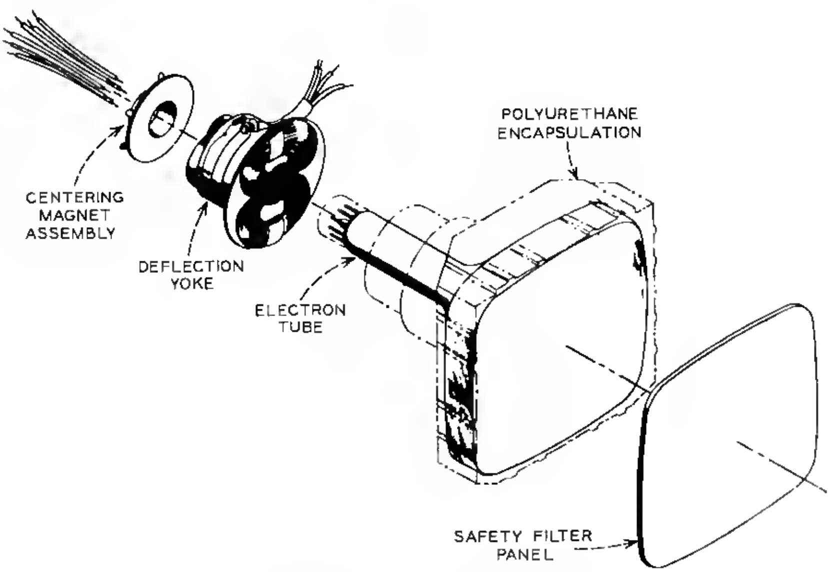

Fig. 8—Close-up view of display tube.

components. The entire package is assembled at the tube manufacturing plant. To improve picture contrast in very bright ambient ligbt, tbe laminated face plate which is applied over the front of the tube for implosion protection incorporates a 30 percent light transmission filter. With this face plate, less than 9 percent of the incident room ligbt is combined with the video display, yet the bighlight brightness can exceed 100 foot lamberts. Finally, the entire assembly shown in Fig. 9 is encapsulated in the previously mentioned polyurethane jacket. This technique, in addition to providing protection from flying glass in the event of an implosion of the bulb, also establishes a firm and reproducible mechanical outline for mounting within the station set. The finisbed unit provides a package of considerable physical strength and replacement of a display tube requires only adjustment of raster size and centering.

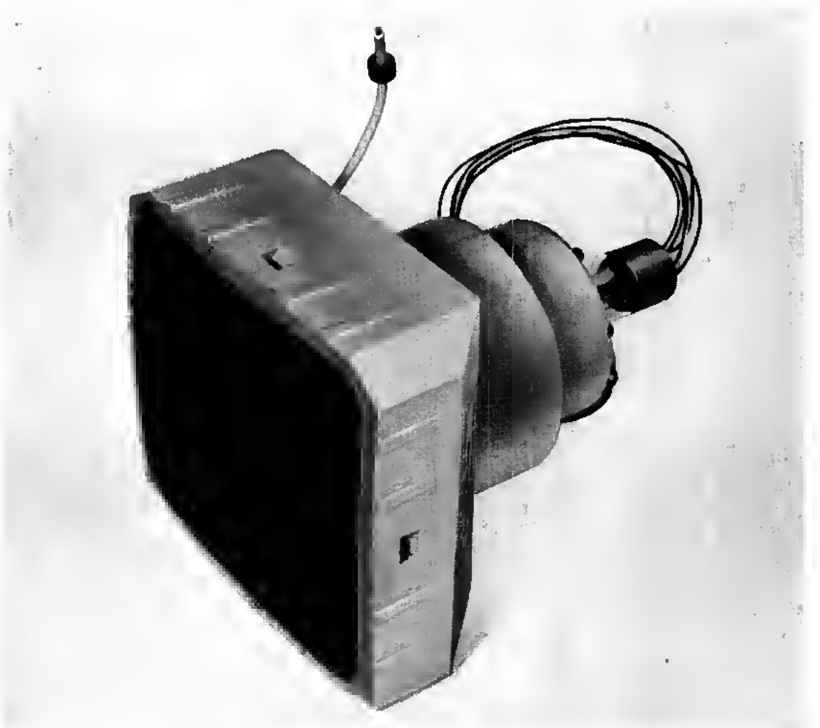

Fig. 9—Assembled display tube.

IV. *Picturephone* TIMING GENERATOR

Locked 2 : 1 interlace and all the timing functions required for transmitter operation are provided by the *Picturephone* timing generator. This circuit consists of a crystal controlled oscillator and five resistor-transistor logic (RTL) circuits mounted on a one-square-incb ceramic interconnection board as shown in Fig. 10. In addition to the 376 transistors, 2 diodes, and 535 resistors which are contained in the six beam-leaded chips, the circuit uses an externally mounted crystal to maintain a stability of better than ± 100 ppm for all timing intervals. This precision allows the pull-in range of the receiver automatic pbase control (APC) circuit to be reduced and permits a substantial reduction in the capacity and cost of the "elastic store" used in the digital coding system. A 12-cell store is used in tbe present coding system[5] as compared to tbe 30-cell store used in the previous design.

The timing functions provided include the following:

(*i*) Horizontal and vertical sweep triggers. These are used for initiating retrace of the beam in the camera.

(*ii*) Camera blanking. This provides cut off of the camera beam during retrace.

(*iii*) Video blanking. This permits disabling of the linear signal-processing chain during the nonvideo intervals.

(*iv*) Sync insertion. This is the composite sync signal that will be mixed with the video information for transmission.

(*v*) Signal analyzer control. This output is used to examine the center half of the picture for light intensity of the scene for setting the automatic gain and iris control (AGIC) of the camera. A distinct pattern which is transmitted when a subscriber goes into the "Privacy" mode is also derived from this signal.

Figure 11 shows the relationship between these various timing waveforms (except the signal analyzer control) and the transmitted composite video. The timing generator derives these timing functions from the crystal controlled oscillator operating at 512 kHz and digital countdown circuitry. 8-kHz horizontal and 59.925-Hz vertical signals are generated by judicious interconnection of the output signals from the various stages of the countdown circuitry.

A block diagram of the timing generator is shown in Fig. 12. The two-stage counter and the first four-stage counter divide the 512-kHz oscillator frequency down to the 8-kHz borizontal line rate. A 16-kHz signal from the first four-stage counter is used to drive the second

four-stage counter. By means of recycling techniques, the second and third four-stage counters divide down to the 59.925-Hz field rate. Various timing intervals available from the intermediate stages of the countdown circuitry are used in the mixing circuits to derive the timing wave forms shown in Fig. 11. The precision of all these signals is derived from the inherent stability of the 512-kHz oscillator.

Low power (1–2 mW/gate), high packing density (85 mils²/gate) and high immunity to power supply variations (2–3 volts) and temperature variations (0–65°C) were the design considerations for the logic circuits. The oscillator circuit was designed around minimum crystal requirements and provides a square wave output with low sensitivity to power supply variations (4–10 volts) and temperature variations (0–65°C). No external capacitors, inductors or manufacturing adjustments are required for oscillator operation.

The total circuit has been realized on six beam-leaded silicon nitride passivated junction isolated chips which are:

(*i*) Crystal controlled oscillator and output buffer circuit
(*ii*) Two-stage counter and mixing circuit.

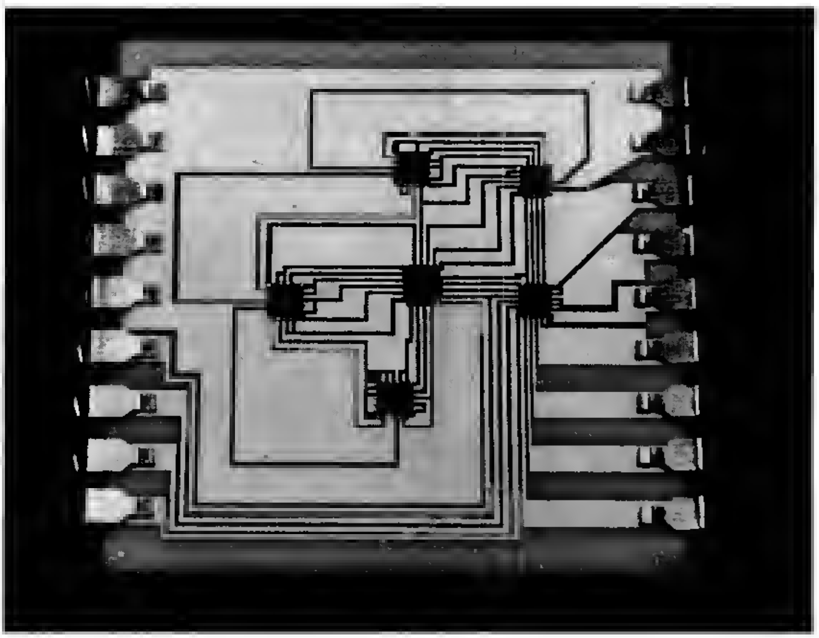

Fig. 10—*Picturephone* timing generator board.

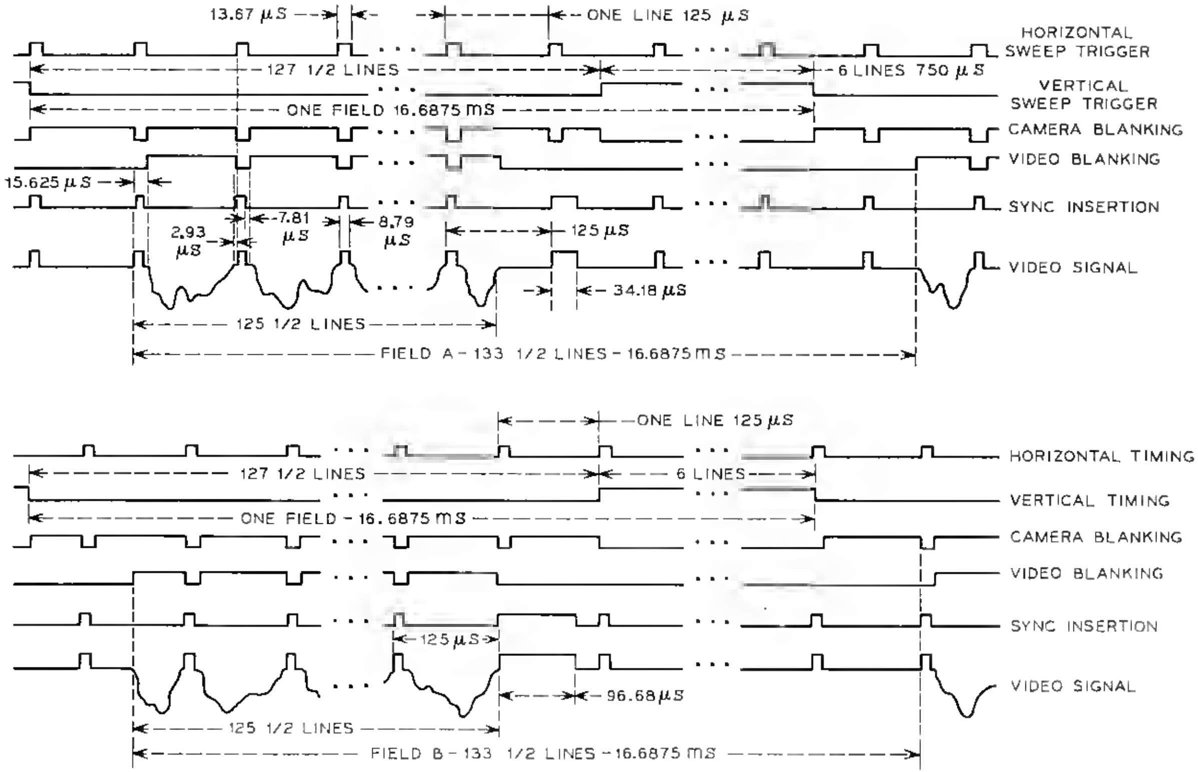

Fig. 11—Timing signals. (The sixth output, signal analyzer control, is "high" during approximately the middle half of the active scan time. One frame: 267 lines—33.375 ms, 251 lines of "picture" information transmitted.)

(*iii, iv, v*) Four-stage counter circuits.
(*vi*) Recycling and output circuit.

4.1 *Crystal Controlled Oscillator and Output Buffer Circuit*

Tbe crystal oscillator circuit provides the fundamental 512-kHz frequency for the timing generator. Its output consists of a symmetrical square wave suitable for driving the integrated logic circuits which count down to the horizontal line and vertical field rates. The oscillator frequency typically deviates from tbe nominal less tban 40 ppm for all causes, including manufacturing tolerances of the amplifier circuit and crystal, a 40°C temperature range, and power supply voltage variations of ± 40 percent.

In addition to the oscillator circuit, buffer transistors for five of the logic outputs are incorporated on the same integrated circuit chip. A total of 13 transistors, 2 diodes, and 24 resistors are contained on the 54×54 mil chip which constitutes this silicon integrated circuit. The total resistance is 43 kΩ and the power dissipation is ahout 70 mW.

The crystal unit consists of a rectangular DT cut quartz plate witb dimensions of 0.350 by 0.140 inches and a thickness of 9 mils. It resonates in a width shear mode which provides a better temperature coefficient than that obtained with square, face shear resonators. Two header wires are attached to the nodal points at the center of the major surfaces of the plate and brought down to a TO-5 header base. Encapsulation of the crystal is achieved by cold welding a 0.6 inch high metal can to the header.

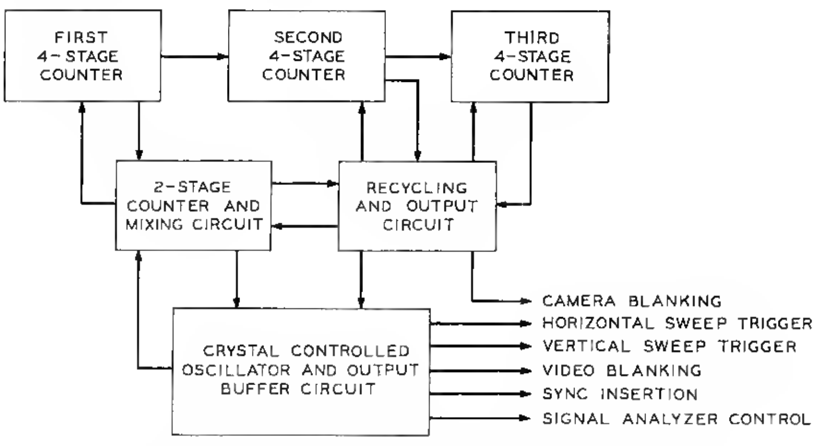

Fig. 12—Block diagram of the *Picturephone* timing generator.

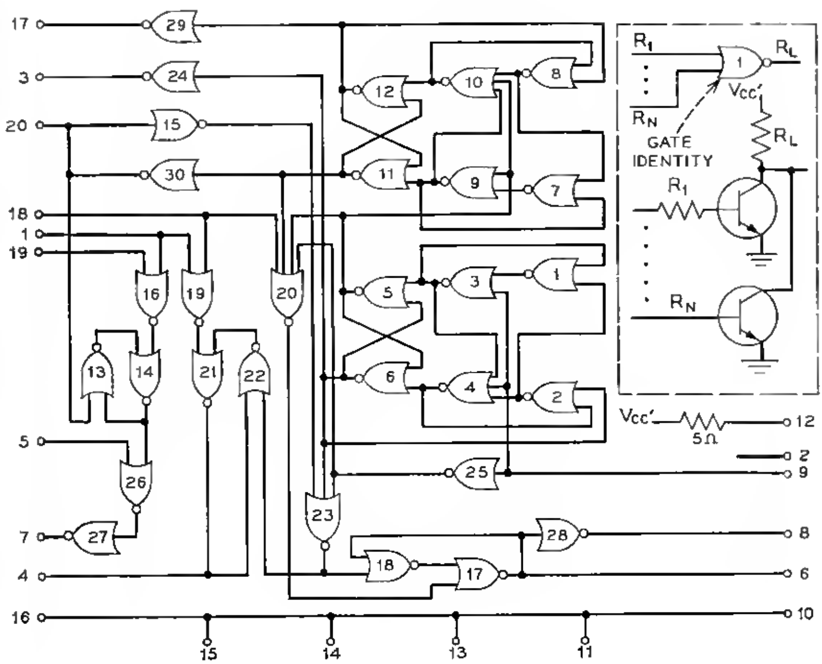

Fig. 13—Logic diagram of two-stage counter and mixing circuit.

4.2 *Two-Stage Counter and Mixing Circuit*

RTL is used in this circuit to derive several logic functions including dividing the input 512-kHz square wave signal by 2 and 4. The horizontal sweep trigger and video blanking signals are also supplied hy this circuit.

As shown in Fig. 13, this circuit contains 30 logic gates composed of 58 transistors and 80 resistors on a 54 × 54 mil chip. Nominal power dissipation at 2.5 V is 50 mW. Each gate was individually designed for fanout to utilize minimum resistor values (therefore low area) for a given power consumption.

4.3 *Four-Stage Counter*

Three four-stage counter circuits are used in the timing generator. Each chip has 38 logic gates containing 79 transistors and 111 resistors. RTL is used to divide the input square wave signal hy 2, 4, 8 and 16. Provision is made for stuffing pulses to control recycling and for gating various state outputs. Nominal power dissipation for the 62 ×

62 mil chip is 60 mW at 2.5 V. A photograph and logic diagram of the circuit are shown in Figs. 14 and 15.

4.4 *Recycling and Output Circuit*

Several functions including camera blanking, signal analyzer control, vertical sweep trigger and the sync insertion signal are derived in this logic circuit. The camera blanking output drives external circuitry directly whereas the other signals drive the output buffer circuits. As shown in Fig. 16, this RTL circuit contains 36 gates composed of 68 transistors and 98 resistors on a 62 × 62 mil chip. Nominal power dissipation at 2.5 V is 60 mW.

V. RECEIVER VIDEO PROCESSOR

In the block diagram of the *Picturephone* station set receiver (Fig. 3), the receiver video processor circuit is enclosed by a dashed line.

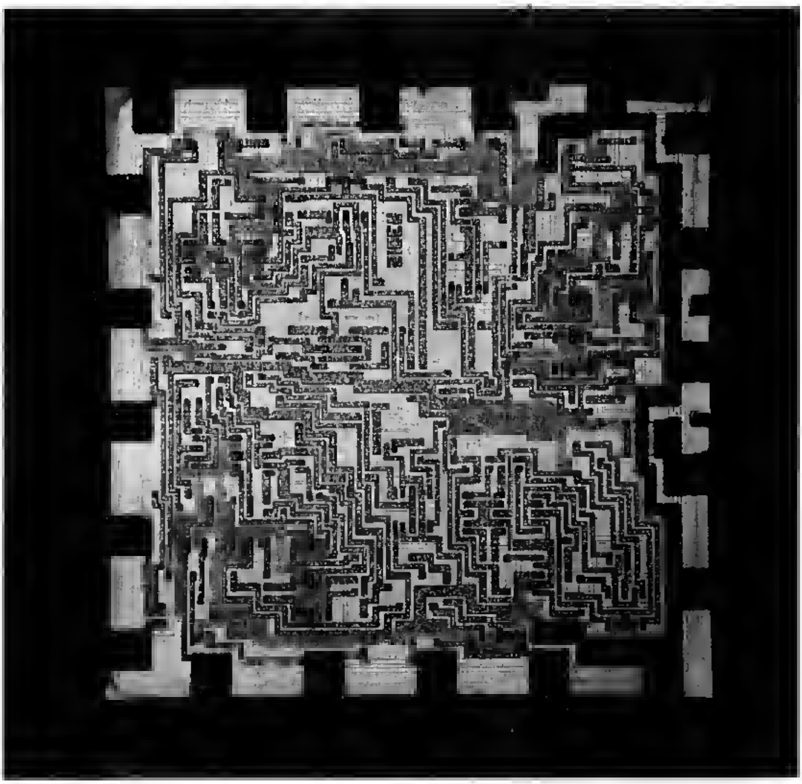

Fig. 14—Four-stage counter.

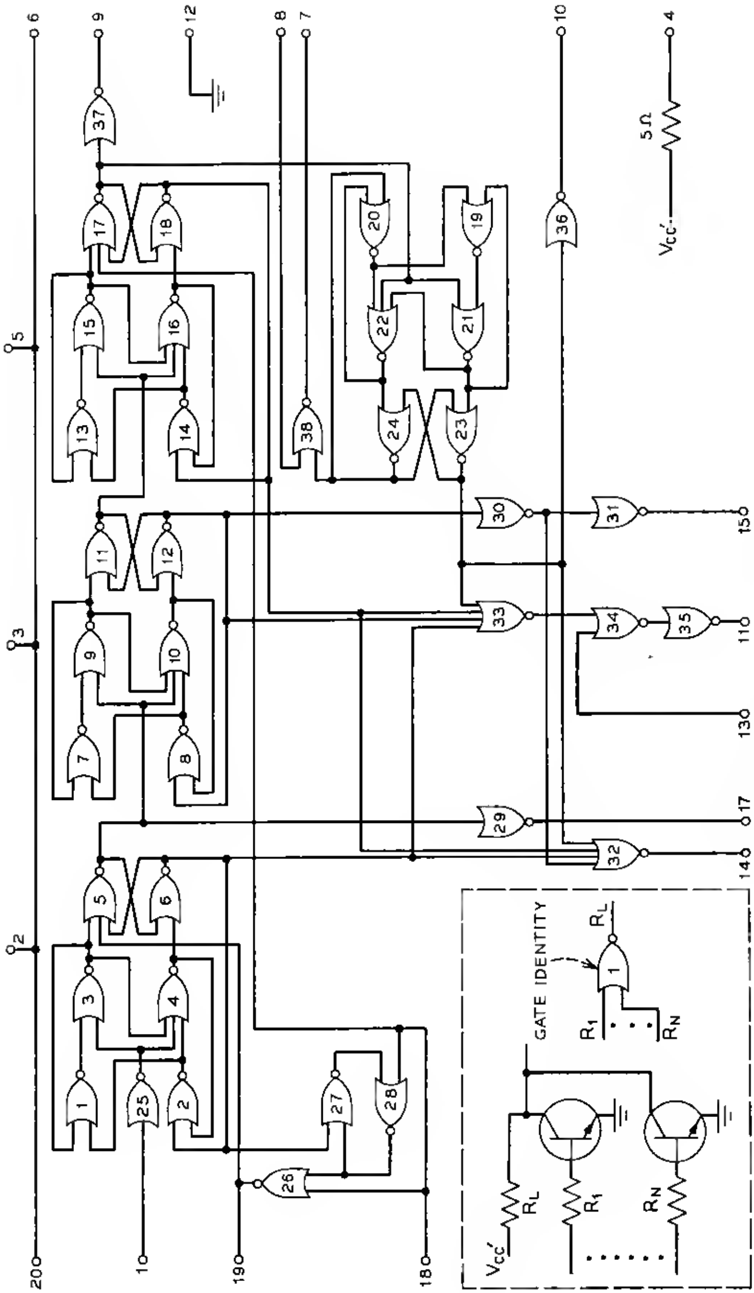

Fig. 15—Logic diagram of four-stage counter.

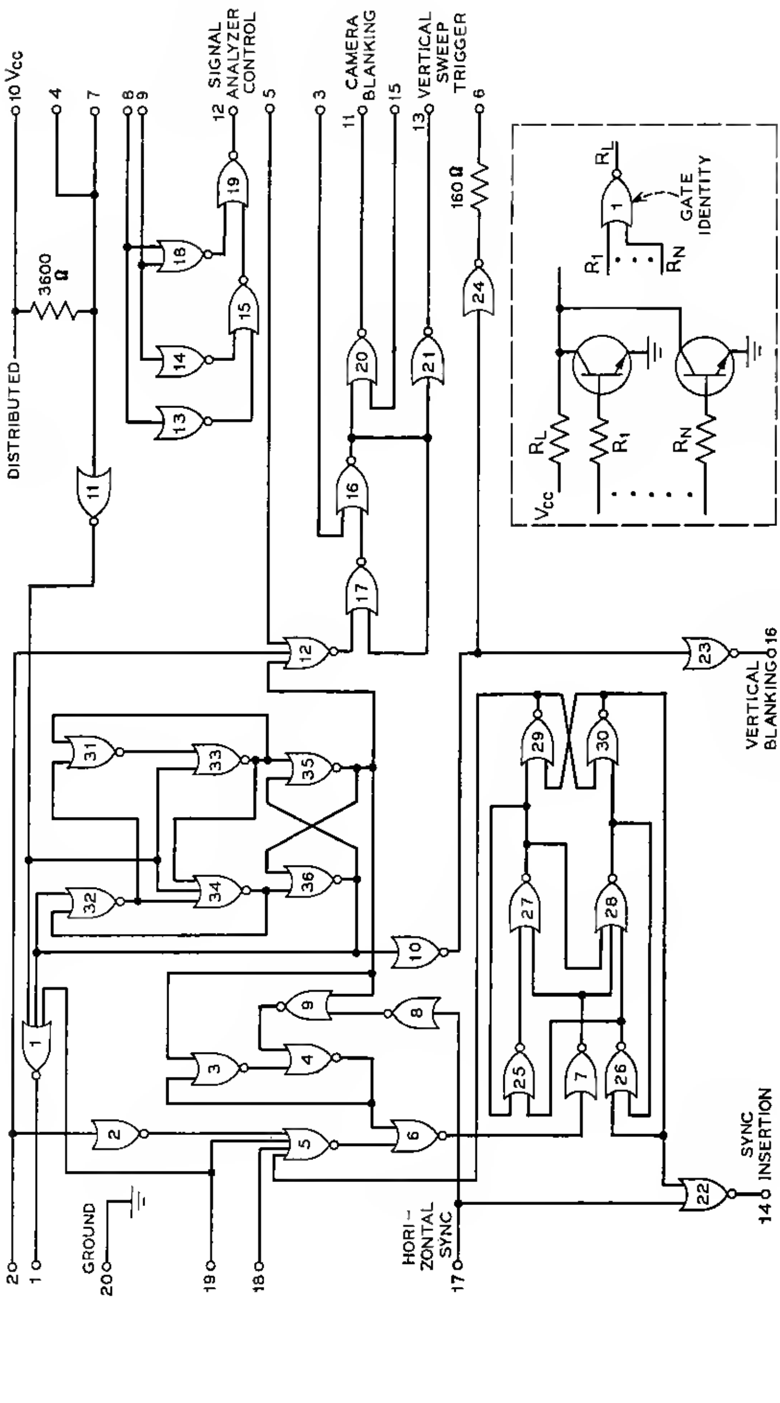

Fig. 16—Logic diagram of recycling and output circuit.

This hybrid integrated circuit (HIC) performs these functions in the receiver of the *Picturephone* station set: (*i*) balanced-to-unbalanced conversion (balun), (*ii*) video switching, (*iii*) AGC (voltage-controlled attenuation), and (*iv*) frequency shaping (bandwidth control and signal crispening).

A photograph of this HIC is shown in Fig. 17. Two beam-leaded silicon integrated circuits, mounted on a ceramic board which includes tantalum thin-film capacitors and resistors on one substrate constitute the total circuit. The balun, video switch, and variable gain stage are integrated on one monolithic silicon chip. Eleven transistors and 11 biasing resistors are incorporated in the second chip as part of the frequency shaping filter. The resistors and capacitors which control the frequency response are on the thin-film substrate.

At the subscriber's premises the analog video signal is received on a balanced twisted pair transmission line.[6] *Picturephone* signals are transmitted in a balanced manner to increase immunity from interference signals. Conversion to an unbalanced signal is performed in the first stage of the video processor by a differential amplifier.

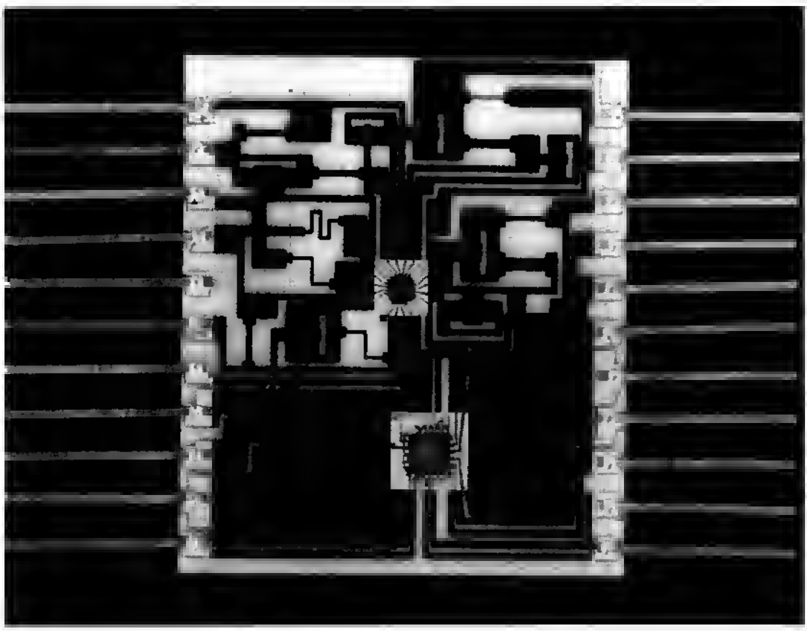

Fig. 17—Video processor board.

The video switch allows the user to view either the outgoing or incoming picture. He selects the mode of operation with his control unit.

Variable attenuation is provided in the last stage of the first SIC. An attenuation range of more than 12 dB is achieved by utilizing the logarithmic ratio of current to voltage in transistors. Total harmonic distortion is less than five percent over the attenuation range for a two-volt peak-to-peak input signal. The three functions have been designed into a 64 $\times$ 64 mil beam-leaded junction isolated silicon chip. It contains 24 transistors, 9 diodes and 54 resistors totaling 147 kΩ and dissipates 160 mW.

An active roll-off filter is used to limit bandwidth and reduce transmission noise. This consists of a six-pole Thomson filter which approximates the ideal linear phase characteristic of a gaussian filter.[7] The crispening circuit accentuates contrast transitions in the displayed picture, which give the effect of an extended bandwidth. Emitter-followers and biasing resistors which isolate the filter stages are on the second SIC. The resistors and capacitors which control the response are of tantalum composition on a ceramic substrate. Final values for the tantalum-film resistors are determined by running a successive-approximation computer program for each production circuit. In effect, each production filter is resynthesized before the chips are bonded down to insure that the particular silicon-tantalum combination is capable of meeting performance requirements. The resistors are then trimmed to the values determined by the computer and finally the silicon chips are bonded to the substrate and the completed assembly is measured. The frequency response characteristic of the filter is shown in Fig. 18. The maximum allowable error is ± 0.5 dB over the frequency range of 0.1 to 1.1 MHz.

In addition to the transistors and biasing resistors for the filter, the second SIC contains metallization paths which interconnect some of the beams to provide crossovers for the external circuit.

VI. VOLTAGE CONTROLLED OSCILLATOR

A voltage controlled oscillator (VCO) which is synchronized with the incoming horizontal signal provides the drive for the receiver horizontal sweep and high voltage supply. An automatic phase control (APC) circuit is employed to reduce jitter and provide immunity from noise pulses. The circuit is in hybrid integrated form on a 0.6 square inch ceramic substrate containing tantalum resistors, 2 silicon chips

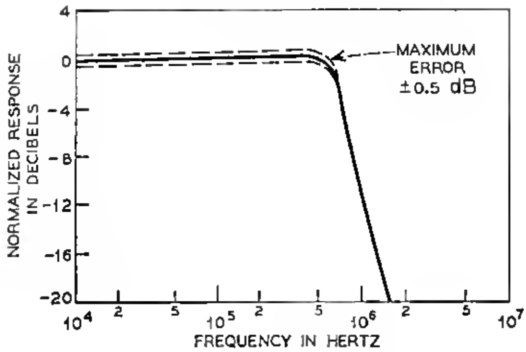

Fig. 18—Filter response.

and a tantalum RC network fabricated on glass for adjusting the oscillator timing intervals. A photograph of this circuit is shown in Fig. 19.

Figure 20 shows the VCO circuit diagram including the integrated and discrete components. Basically, the VCO consists of an oscillator under the control of an APC circuit. This oscillator is composed of one SIC and a tantalum thin-film resistor-capacitor network and functions as a temperature compensated astable multivibrator. A 42 ×

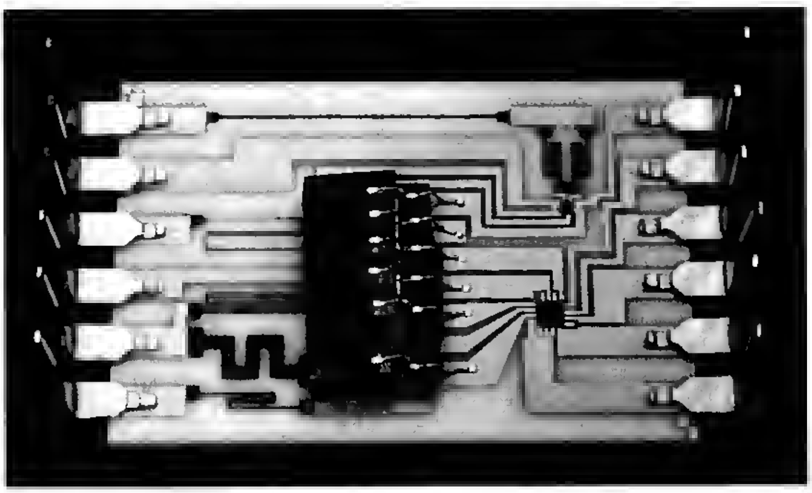

Fig. 19—Voltage controlled oscillator.

42 mil beam-leaded junction isolated chip containing 8 transistors, 5 diodes, and 10 resistors totaling 39 kΩ constitute this SIC. Nominal power dissipation is 70 mW.

A sawtooth type phase comparator is used in the APC circuit to derive a control voltage from the phase difference between the incoming horizontal sync signal and the horizontal signal derived in the receiver oscillator. The control voltage developed in the phase lag filter is near ground potential and can he used directly to control the oscillator but with the penalty of affecting the time constants of the oscillator. By introducing the level shifter shown in Fig. 20, in which the resistive elements are in tantalum thin-film form, the effects of interconnecting the discrete and integrated circuits are buffered out. Essentially unity gain for the control voltage and a dc shift of approximately +5 volts is achieved with the level shifter. A matched pair of transistors is used for the two active elements of the level shifter to take advantage of their matched V_{BE}'s and temperature characteristics.

In manufacture, the oscillator RC network and the resistors for the level shifter are trim anodized to value, except for R_{1G} and R_{4G} . These two elements are adjusted after the two silicon chips and the glass sandwich containing the tantalum components for the oscillator are mounted on the ceramic interconnection hoard which also contains

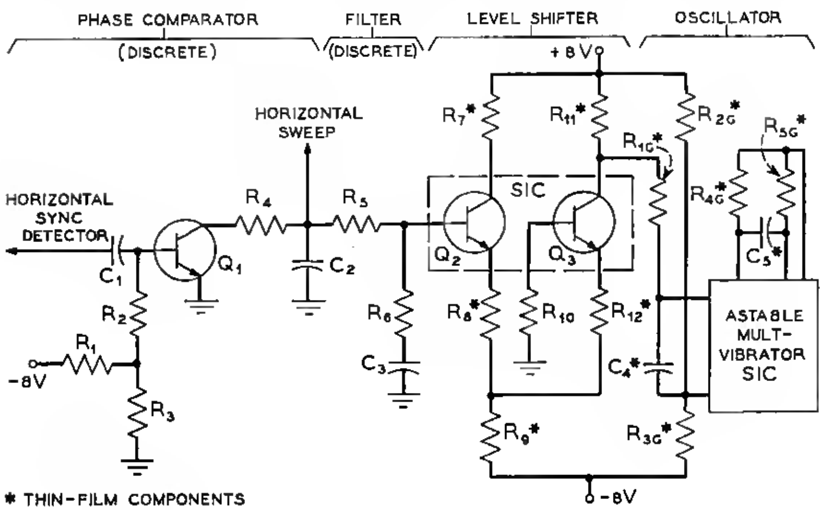

Fig. 20—Voltage controlled oscillator.

the resistors for the level shifter. R_{4G} is trim anodized to provide a 19.5-μs ($\pm$1 percent) timing interval and R_{1G} is trim anodized to provide an 8050-Hz ($\pm$0.5 percent) repetition rate. Both inputs of the level shifter are terminated in separate 23.7-kΩ resistors to ground while these adjustments are made. In normal operation, the control voltage will experience very small deviations. The sensitivity of the oscillator is such that a change in control voltage of $\pm$0.1 volt results in a change in frequency of approximately $\pm$80 Hz.

VII. OFF-HOOK AND RING DETECTOR

This circuit, shown in Fig. 21, is bridged across the balanced telephone line to detect an off-hook condition and to detect ringing. Whenever a video call is received, the output from the ring detector is combined logically with other signals to activate a ringing signal generator. The circuit is included in the service unit for station sets used with non-key telephones; for key telephones this function is performed in the common key equipment. Thin-film technology is used because the comparator circuit requires careful balancing to detect the transverse signals and provide good common mode rejection. A well balanced amplifier is achieved by trim anodizing tantalum nitride thin-film resistors to $\pm$1 percent in combination with a matched pair of transistors.

The resistor values required range from 200 Ω to 121 kΩ a ratio of 1 : 605. Design considerations for the low value resistors differ from those of the high value resistors. However, by appropriate selection of line widths and sheet resistivity, it is possible to fabricate all resistors from a single uniform tantalum nitride film. Because two 121-kΩ resistors are required, a final sheet resistance of 100 Ω per square and 5 mil wide paths were chosen to keep the required surface area as small as possible. Thirty mil wide paths were chosen for the 200-Ω resistors to provide an effective area for anodization. Once the final sheet resistance had been chosen as 100 Ω per square, the initial sheet resistance required for the sputtered tantalum nitride material was calculated to be approximately 50 Ω per square. This allowed for a large enough anodizing voltage to provide the benefit of oxide protection and an adequate trimming range. Individual resistors for all 15 circuit modules on a substrate are trim anodized to $\pm$1 percent in the absence of the SICs. The 15 circuits are then separated, the integrated circuits are appliquéd, and the completed modules tested. Figure 22 shows a 0.8-square-inch completed circuit with lead frames attached.

VIII. OPERATIONAL AMPLIFIERS

8.1 *High Output Voltage Swing Operational Amplifiers*

Three operational amplifiers were designed to meet the frequency response and output voltage swing requirements for eight applications in the *Picturephone* station set. All three codes have a heam-leaded silicon chip of the same hasic design honded to a 16 lead dual-in-line ceramic suhstrate. Three different test specifications are utilized to reflect the various requirements for the eight applications.

The hasic circuit is designed with optional Darlington inputs and operates from ±8.0-volt power supplies. In one operational amplifier, the Darlington inputs are externally conncted to provide high input impedance (> 1 MΩ), low hias current, and low offset current (< 20 nAdc). These characteristics are needed for applications in hoth the camera horizontal and vertical sweep circuits. In addition, this operational amplifier provides a minimum output drive current of 10 mA into a 600-Ω load for the vertical sweep circuit.

Another version of the operational amplifier is used in the receiver video and sync amplifier circuits and in the camera video amplifier. In

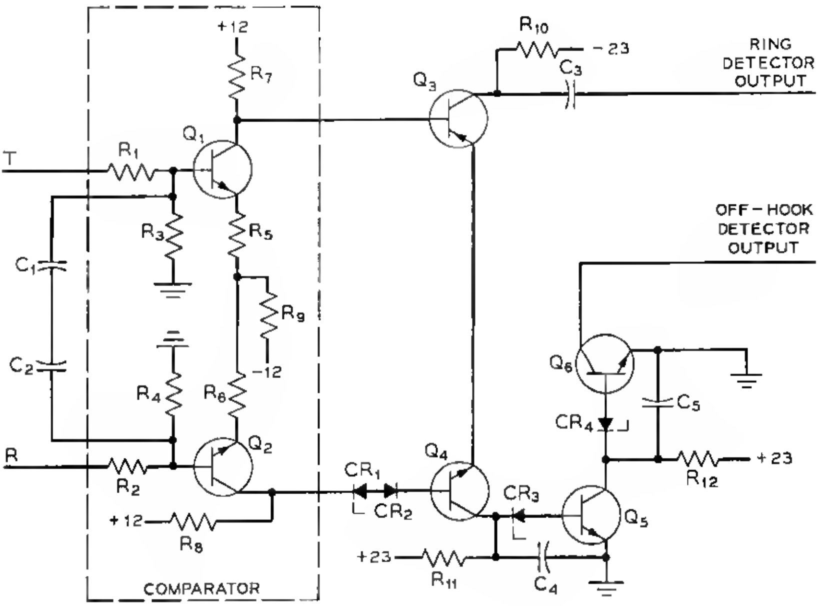

Fig. 21—Off-hook and ring detector schematic.

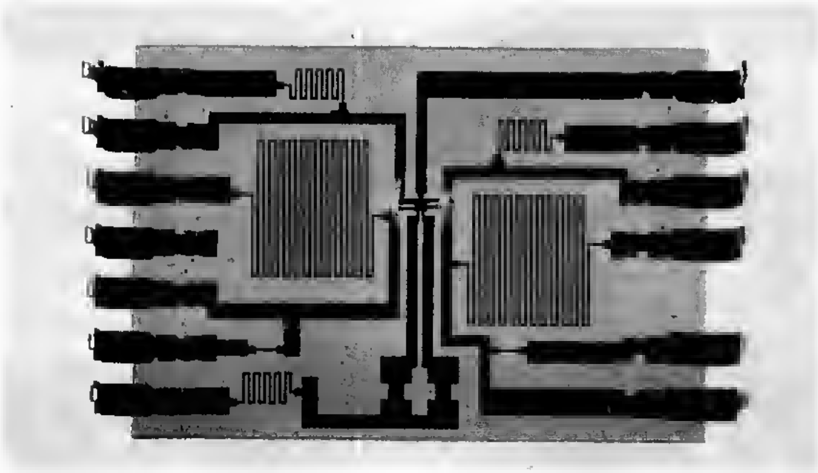

Fig. 22—Off-hook and ring detector comparator.

order to achieve a stable, flat (to ± 0.1 dB) frequency response beyond 1 MHz with a 12-volt peak-to-peak output swing, the non-Darlington input connections are used. Additionally, both this and the previous version of this operational amplifier provide a low offset voltage (< 3 mVdc).

The third version of this operational amplifier is used in the audio portion of the *Picturephone* station set. Two of these operational amplifiers are used in the audio preamplifier and one in the auxiliary amplifier for the speech circuit. The non-Darlington inputs are used to insure high open loop gain (typically 82 dB). Noise voltage with C-message weighting is less than -114 dBV.

All of these operational amplifiers are fabricated using junction isolation and beam-lead, sealed junction technology on a 46×46 mil chip with 16 beam leads. Each chip has 14 npn transistors and 14 resistors totaling 64.2 kΩ. A picture of the chip is shown in Fig. 23.

8.2 *General Purpose Operational Amplifier*

This operational amplifier was designed for general Bell System use. As used in the *Picturephone* station set, it serves as a voltage comparator in the transmitter automatic gain and iris control (AGIC) circuit. The amplifier is mounted in a dual-in-line package (DIP) and as a voltage comparator has a closed loop gain of 32 dB. Pertinent properties of this device which are required for application in the AGIC circuit are:

Input bias current	$< 2.2\ \mu A$,
Power supply voltages	$\geqq \pm 12$ V,
Common mode input voltage	> 4.5 V,
Output swing	± 10 V.

To increase the positive output swing capability and insure full closure of the iris (when required), the output stage is bypassed. This is accomplished by tying several leads together via the metallization on the ceramic portion of the DIP. Bypassing the output stage also reduces the power dissipation on the chip from 290 mW to 240 mW.

IX. BUILDING BLOCK SIC

To meet the need for multiple matched transistors in the station set circuitry, a building block SIC was developed. This SIC con-

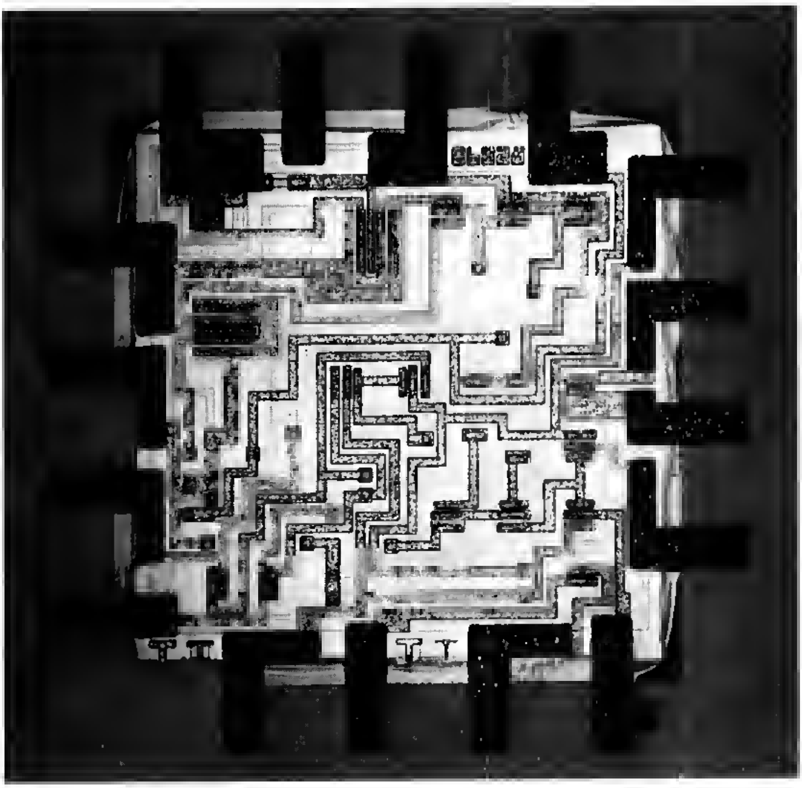

Fig. 23—High output voltage swing operational amplifier.

sists of six transistors connected in the following fashion: Two of the transistors are connected as a Darlington pair, two transistors are connected as a cascode pair and the elements of two transistors are brought out separately. This SIC is used in seven station set circuits:

(*i*) camera pre-amp,
(*ii*) transmitter sweep circuits,
(*iii*) receiver video clamp,
(*iv*) receiver sync clamp-AGC lock up protection,
(*v*) receiver AGC comparator,
(*vi*) receiver AGC comparator—video clamp, and
(*vii*) receiver vertical sync.

Beam-lead sealed junction technology is used to fabricate this circuit which is supplied in a DIP.

X. AUDIO POWER AMPLIFIER

An audio power amplifier SIC was designed for use as the station set speaker driver. This circuit consists of a differential input stage, level shifter, and power output stage capable of outputs in the $\frac{3}{4}$ watt range. Internal feedhack resistors are used to set the gain of the amplifier but this can be adjusted with an external resistor. The high swing output stage operates in class AB and utilizes matched high power interdigitated transistors capable of peak currents of 500 mA. Approximately 9 mA of quiescent current flows in the entire amplifier.

Sealed junction technology is used to fabricate this SIC on a 64×68 mil chip. Five large area high power interdigitated transistors, three medium power transistors, seven low power transistors, and 13 resistors totaling 44.8 kΩ constitute the circuitry. A photograph of this chip is shown in Fig. 24. The chip is mounted in a 10-lead TO-55 type header with a molybdenum heat spreader. When mounted in the station set a heat sink is attached to aid in heat dissipation.

XI. VOLTAGE REGULATOR

A precision bybrid integrated voltage regulator was specifically designed for the *Picturephone* station set. Three of these integrated circuits are used in each station set; two on the receiver circuit board and one on the transmitter circuit board. Essentially all the linear and synchronization circuits on the receiver circuit board utilize the ± 8 volts provided by its two integrated regulators. This includes the

following circuits: balun-video gate–AGC, roll-off filter and crispening circuit, video display amplifier and clamp, timing amplifier and clamp, vertical and horizontal synchronization circuits, AGC comparator, AGC sampling circuit, AGC lock-up protection circuit, sync separator and the sync gate. The regulator on the transmitter circuit board provides +8 volts to the gamma correction, pre-emphasis, sync insertion, vertical and horizontal sweep drive, and crystal oscillator circuits, and to the camera tube and display tube filaments.

A schematic of the regulator SIC is shown in Fig. 25. Basically it consists of a reference diode (D4), an error amplifier (Q4-Q5), and an output stage (Q1-Q2). Currents of approximately 0.5 mA each are provided to terminals 2 and 10 from external circuitry. Since the output current of this SIC is rated at 30 mA, an external medium power transistor is utilized with each one to achieve the desired higher output current needed in the *Picturephone* station set. By inserting the output device within the feedback loop of the error amplifier, the regulating properties of the SIC are maintained.

To assure almost instant operation of the *Picturephone* station set

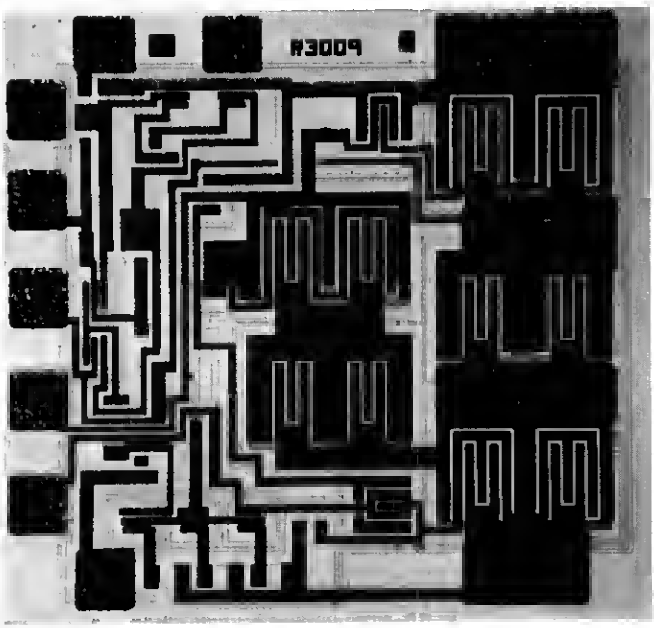

Fig. 24—Audio power amplifier.

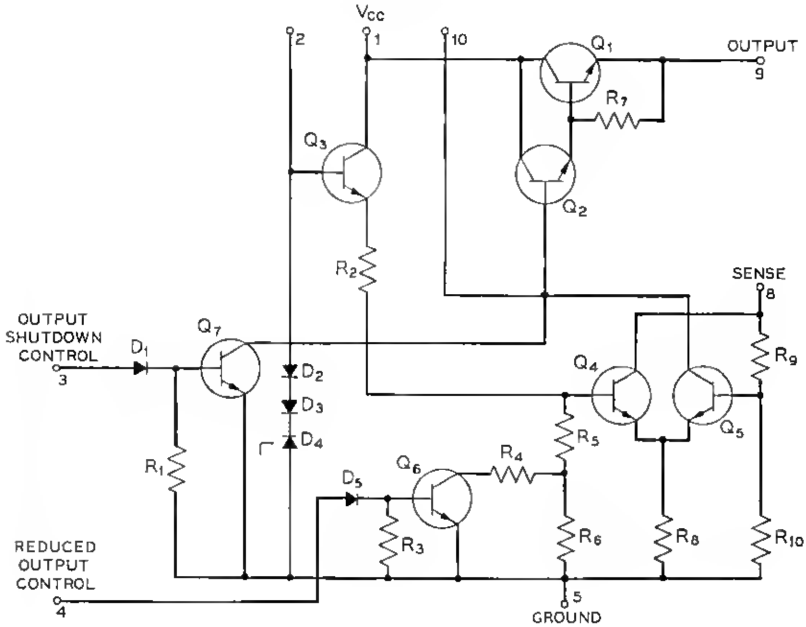

Fig. 25—Voltage regulator.

when a call is initiated or answered, the filament voltages of the camera and display tubes are maintained at 90 percent of their operating voltages during standby periods. This is achieved by supplying a positive control signal (during standby) to terminal 4 of the SIC used on the transmitter board.

During manufacture, the output voltage is set to 8 volts ±1 percent for simultaneous worst-case conditions of line, load, and temperature variations. The output impedance is less than 1.5 Ω, the ripple attenuation is greater than 23 dB, and the output noise (10 Hz to 10 MHz) is less than 0.15 mV rms over the operating temperature range of 10° − 65°C.

The precise output voltage is achieved by matching a monolithic integrated circuit chip to a discrete reference diode. Both devices are eutectic bonded to a molybdenum platform in a 10 lead TO-55 package. The molybdenum platform insures temperature matching of the reference diode and the monolithic SIC. Both the reference diode and the SIC utilize standard nitride sealed junction and beam-lead technologies.

XII. QUAD "NAND" GATE

The off-hook and ring detector used with non-key telephones was described earlier. Its outputs drive logic circuits which activate the proper equipment. To perform these logic functions, two flip-flops, one three-input "NAND" gate, one two-input "NAND" gate and two inverters are required. Using "NAND" type logic, these functions are obtained very efficiently with two identical SICs without any external components.

The SICs used are one of a family of diode transistor logic (DTL) units developed for the 810A PBX to provide positive logic "NAND" functions. It is especially suitable for use in the *Picturephone* station set because of the following properties.

(*i*) It has a high dc noise margin because of its relatively high switching threshold of 1.8 volts.

(*ii*) It operates at relatively slow speed with a propagation delay of 0.5 μs. This makes the unit less sensitive to high frequency noise pulses.

This SIC is a 54 × 54 mil beam-leaded junction isolated chip mounted on a ceramic substrate (0.625 inches × 0.35 inches substrate with 16 external leads). When used to its full capability, it provides three two-input and one expandable three-input gate each having a maximum fan out of five. Figure 26 shows the logic diagram and basic gate schematics for this SIC. As used in the *Picturephone* station set with a 4.7-volt power supply, the unit dissipates 110 mW.

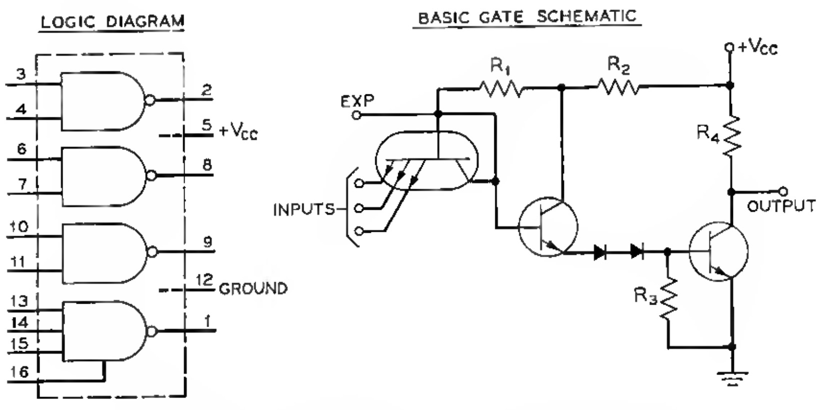

Fig. 26—Quad "NAND" gate logic and schematic of gate.

XIII. DISCRETE DEVICES

Most of the more than 200 discrete solid-state devices in the station set are general purpose Bell System units originally designed for other projects. In addition, several new discrete devices were required to meet special operating conditions in the *Picturephone* station set. These will be described in this section.

13.1 *Power Transistor*

In order to hold size variations to a minimum, the horizontal sweep circuit of the receiver requires about 1.0 ampere from a well regulated 18-volt supply. An npn transistor with the following properties is required for the output stage of the regulator:

$$\begin{array}{ll} \text{With } I_c = 1\text{A}, & h_{FE} \geqq 50; \\ \text{and } T_j = 25°\text{C}, & V_{CE}(\text{SAT}) < 0.80 \text{ V}, \\ & V_{CE}(\text{SUS}) \geqq 20 \text{ V}; \\ & \text{Power Dissipation} \geqq 5 \text{ watts}. \end{array}$$

A power transistor was designed to meet these requirements. It consists of a planar silicon chip with 700 mils of emitter perimeter and 3,300 square mils of base-emitter junction area. The device is housed in a TO-32 package which has a junction to case thermal resistance of 2°C per watt. This provides a power capability considerably in excess of that required for this application.

An epitaxial silicon layer was not used in the design of this device to avoid potential secondary breakdown problems. A value of resistivity was chosen to allow the current gain and sustain voltage requirements to both be satisfied. To improve reliability, an in-process power screen for two hours is performed to remove early failures caused by hot spots. Reliability tests on screened product indicate that failure rates of less than 10 FITS may be expected for this device as used in the *Picturephone* station set.

13.2 *Medium Power Silicon pnp Transistor*

Both the horizontal sweep circuit in the transmitter and the vertical sweep circuit in the receiver employ push-pull output circuits for driving their respective yokes. Each output stage requires a complementary pair of medium power devices. Existing Bell System transistors were found to be satisfactory for the npn applications. A medium power device was designed for the pnp applications and utilizes a planar epitaxial structure with silicon nitride protection and beam-lead

metallurgy contacts. The transistor chip is mounted in a TO-38 package which has a junction to case thermal resistance of 6.5°C per watt. Basically this transistor is an enlarged version of an existing low-power npn transistor designed to meet higher current and power dissipation requirements.

13.3 *High-Voltage Silicon Transistor*

The station set display tube is driven with the video signal applied to its grid. Two pnp transistors with their collectors tied together constitute the driver stage. One transistor provides the video signal under normal conditions and the second device, in the absence of an incoming signal, provides a gray raster signal to the receiver. For this application, the transistors must meet the following end-of-life requirements:

$BV_{CEO} \geqq 90$ V at $T = 0$ to 65°C,
$h_{FE} \geqq 20$ at $0.1 \leqq I_c \leqq 5$ mA and $V_{CE} \geqq 10$ V,
$h_{fe} \geqq 20$ at I_c of 0.1 mA and 6 mA at 1 MHz,
$I_{CBO} < 100$ nA at $V_{CE} = 5$ V,
$V_{CE}(\mathrm{SAT}) < 0.5$ V,
$C_{ob} < 3$ pF at $V_{CB} = 5$ V,
Power dissipation—less than 180 mW peak power and 130 mW normal power.

The device developed for these applications utilizes the basic structure of an existing low-power npn transistor. By making appropriate changes in the impurity profile, the high-voltage characteristics and low-current gain capability were achieved. A 6-mil-thick wafer with 10 Ω-cm resistivity was used for the starting material. This planar epitaxial silicon transistor uses beam-lead metallurgy contacts and silicon nitride protection. Initially, the devices were provided in TO-18 packages, but later units have been encapsulated in plastic similar to the TO-92 package.

13.4 *Field Effect Transistor*

An n-channel silicon planar epitaxial junction field effect transistor (JFET) is used as a shunt variolosser in the transmitter AGIC circuitry. The signal from the integrated voltage comparator is applied to both the iris and the gate of the JFET. Under high-light conditions the signal from the comparator circuit decreases the bias on the iris control which in turn closes the iris. Simultaneously this signal maintains the JFET in its saturation region and provides minimum gain in the video amplifier. As the scene luminance is decreased,

the iris opens to its widest position. For further reductions in scene luminance, the JFET comes out of its saturation region and serves as a higher shunt resistor for the amplifier input so as to provide up to 6 dB of additional gain.

This JFET is mechanically the same and electrically similar to a JFET developed for use in the N2 and N3 Carrier Systems. For this *Picturephone* application, the device meets tighter requirements on pinch off voltage, R_{DS}, and saturation drain current.

An additional JFET is used in the camera tube preamplifier circuit and satisfies the requirements of low noise, high-input impedance and low capacitance needed for this application. Except for specifications on V_{GS}, I_{DSS}, and g_{fs}, these devices are also similar to units developed for the N2 and N3 Carrier Systems.

XIV. PURCHASED DEVICES

Several devices used in the receiver horizontal sweep circuit and high-voltage supply are not manufactured by Western Electric Company. These devices are purchased from various suppliers to meet Western Electric specifications. Although these devices are similar to units manufactured by these suppliers for the industrial market, the specifications reflect electrical parameters and reliability consistent with Bell System standards. These devices are discussed below.

14.1 *Sweep Transistor*

This device is a high-voltage germanium alloy pnp power transistor which is housed in a TO-3 package and has a junction to case thermal resistance of 1.5°C per watt. It is used for two applications in the receiver horizontal sweep circuit as shown in Fig. 27. In one application (Q1), the device serves as a switch to reverse the sweep current in the horizontal yoke. When the transistor is turned off, the flyback pulse of 250 volts appears across the device and the primary winding of the high-voltage transformer which develops the ultor voltage. To insure against excess power dissipation in the transistor at the start of the flyback pulse, the transistor must turn off quickly. The current gain and saturation voltage limits were imposed by worst-case operating conditions.

Pertinent end-of-life requirements are given below:

$I_{CES} < -24$ mA at $V_{CE} = -310$V,
$V_{CE}(SAT) < -0.5$V at $I_C = -8$A and $I_B = -0.4$A,
$h_{FE} > 20$ at $I_C = -8$A and $V_{CE} = 0.75$V,
$t_{OFF} < 0.75\ \mu$s for $I_{C1} = -8$A, $I_{B1} = -0.4$A, and $I_{B2} = 0.5$A.

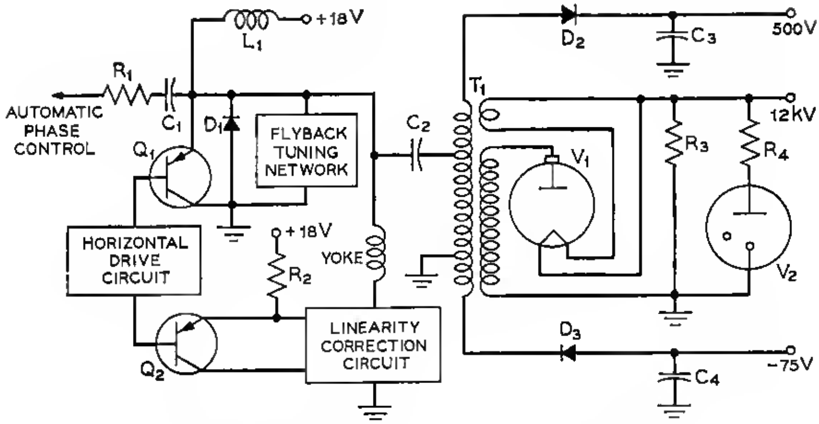

Fig. 27—Receiver horizontal sweep and high-voltage supply.

In the second application (Q2), the device serves as a switch in the linearity correction circuit. A one-ampere current pulse is conducted by the device during the horizontal retrace interval. Requirements imposed by this application are readily met by the specifications listed above.

14.2 *Electron Tube Diode*

The flyback pulse that appears on the primary of the high-voltage transformer (T1) shown in Fig. 27 is stepped up to 16 kV (open-circuit) on the secondary winding. This pulse is then rectified to develop the dc ultor voltage for the display tube. Rectification is performed by a miniature filamentary high-voltage electron tube diode (V1). Filament power for the tube is provided by a single winding on the secondary of the transformer. Since the tube has a directly heated cathode, the filament is maintained at the dc cathode voltage. An electron tube rather than a solid-state device was chosen for this application because of the faster switching time, lower cost, and adequate reliability provided by the tube.

14.3 *Corona Regulator*

The display tube picture has a requirement of ±1 percent on horizontal size and aspect ratio. Since the raster size is inversely proportional to the square root of the ultor voltage, this potential must possess a stability of ±2 percent. This stability was achieved by em-

ploying a gas filled high-voltage regulator (V2) as shown in the circuitry of Fig. 27.

As shown in Fig. 28, the tube consists of a cylindrical metal shell (cathode) with a projecting ceramic insulator which is capped with a metal terminal (anode) designed for plug-in connection with a mating receptacle. The breakdown voltage of the device is controlled by the internal gas pressure. For voltages below breakdown, no current flows. If the voltage is slightly above the breakdown voltage, considerable undesirable noise is generated as current starts to flow. Also, voltage spikes referred to as "pips" can occur. As used in the *Picturephone* station set, the tube must draw greater than 25 μA to get beyond this noise region. A series resistor is employed to prevent the tube from reaching its glow discharge region (> 1000 μA) due either to supply voltage transients or pips.

In the station set, the tube is operated in the corona mode of discharge with a current range of 25 μA to 200 μA. The higher current occurs for a dark displayed picture and the lower current occurs for a bright picture. For this range of current, the voltage variation is at most 250 volts. The breakdown voltage of the tube at 75 μA is specified as 12.0 ± 0.3 kV. During manufacture of a station set, the regulator tube is installed and the horizontal size and aspect ratios are set within specifications by adjusting their respective controls. As the displayed picture brightness is varied the regulator tube maintains the size and aspect ratio within tolerance.

XV. PASSIVE COMPONENTS

Although solid-state technology has been utilized throughout the

Fig. 28—Corona regulator.

station set design, a substantial number (over 650) of discrete passive elements are employed.

Because of size and cost considerations, the use of inductors has been kept to a minimum. Resistors and capacitors are either coded Western Electric components or are obtained from other suppliers under Western Electric specification. Two types of resistors are of special interest. The first is a 3000 MΩ high voltage ±5 percent metal oxide film resistor. By shunting it across the 12-kV ultor supply, it serves as a bleeder resistor to remove the charge from the ultor supply after the set is turned off.

The second type is the tantalum resistors constituting over half of the discrete resistors used in the station set. Each consists of a tantalum nitride film of appropriate thickness and geometric pattern sputtered on the embossed face of an alkaline earth porcelain substrate. The substrate dimensions are 0.35 inches by 0.10 inches plus two external leads. These resistors are rated at $\frac{1}{8}$ watt at 70°C and $\frac{1}{4}$ watt at 40°C and are available with ±3 percent and ±1 percent tolerances. Because of their small size, low cost, and good stability (< 1 percent change in resistance after 20 years), they provide an excellent means for obtaining accurate signal levels.

XVI. CONCLUSIONS

Development of the *Picturephone* station set has required the design of a considerable number of state of the art solid-state and electron-tube devices to meet critical performance and cost objectives. Where available, satisfactory existing devices were used. Integrated circuits were used judiciously to take full advantage of their attributes.

XVII. ACKNOWLEDGMENTS

Developing components on schedule for the station set has been a demanding task which has required the closest type of cooperation between Systems Development and Device Development areas. The number of people involved in both areas has been large and we acknowledge their dedication and cooperation in making the *Picturephone* station set possible.

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